Radiological Risk Assessment of a Thorium Rich Area in Norway

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Abstract: Human risk assessment in present study was carried out on the basis of the measured absorbed doses in air due to outdoor gamma as well as ^{222}Rn and ^{220}Rn concentrations at the Fen Complex region, a well-known thorium rich area in Norway. Cancers (solid cancer, leukaemia and lung cancer) were considered as the assessment end-points. Assuming an outdoor occupancy factor of 0.2 (1752 hrs per year), the mean estimated annual effective gamma outdoor doses ranged from 0.36-2.48 mSv. The risk of solid cancers and leukaemia were estimated to be 0.0001-0.001 and 0.001-0.01 respectively. The mean estimated annual equivalent doses to lung due to ^{222}Rn and ^{220}Rn exposure ranged from 0.6-1.78 mSv and 0.03-0.52 mSv respectively. The corresponding excess relative risks of lung cancer from ^{222}Rn and ^{220}Rn exposures varied from 0.0001-0.0004 and 0.00002-0.0004 respectively. The doses in the FC region are likely to pose public risks, and therefore, the high dose sites require interventions.

1. INTRODUCTION

According to the UNSCEAR, radon inhalation makes up half of the total global average public exposure to natural radiation [1]. There are two co-existing radon isotopes viz; radon (^{222}Rn) and thoron (^{220}Rn) that are daughter products of uranium (^{238}U) and thorium (^{232}Th) series respectively. It is obvious that numerous studies on radon exist [2], however, thoron has been paid a limited attention [3]. The respective doses from the radon isotopes and their progeny largely vary according to the ratios of ^{238}U and ^{232}Th concentrations in the soil. There are many areas worldwide with the higher ^{232}Th levels and such areas are of interest from the perspectives of ^{220}Rn exposures. One of the world's largest thorium reservoir sites is located in Telemark County, 120 km southwest of Oslo, Norway [4]. The area, called the Fen Complex (FC), is situated close to a small town Ulefoss and lake Norsjø. Due to the elevated concentration of thorium in the rocks of the FC area [4, 5], it might be considered for excavation and mining in the future. The area was mined in the past for iron and niobium during 1650-1930 and 1953-1965 respectively [5]. As a result of that, the tailings containing ^{232}Th and ^{238}U in the area were also reported to give significant gamma doses [6].

The aims of the present study were to estimate doses and risk for cancers among human population in the FC region due to the exposure to outdoor gamma, ^{222}Rn and ^{220}Rn. The gamma doses were assessed for any possible solid cancers and leukaemia while ^{222}Rn and ^{220}Rn doses were assessed for lung cancers.

2. MATERIALS AND METHODS

The areas studied in the FC comprised TENORM sites (Bollodalen, Fengruve, Gruvehaugen and Søve) and a NORM site (Rullekoll). Most of these sites were located in the forest area. The GPS coordinates ranged from N59º16.40´; E09º18.40´ to N59º16.90´; E09º17.16´. Outdoor gamma absorbed doses (mGy) as well as simultaneous ^{222}Rn and ^{220}Rn concentrations (Bqm^{-3}) were measured with TLD-IJS-05[CaF_2: Mn] type thermo luminescent dosimeters and Raduet® detectors respectively during June-September 2010. All the measurements at the FC were performed at the distance of one meter above the ground

level. The TLD doses and ^{222}Rn and ^{220}Rn concentrations were read at Jožef Stefan Institute, Ljubljana, Slovenia and National Institute of Radiological Sciences, Chiba, Japan respectively.

Annual effective doses were estimated from the absorbed doses using the conversion factor 0.7 SvGy^{-1}[7]. The gamma dose risks were estimated assuming the excess relative risks of solid and leukaemia mortality were 0.4Sv^{-1} and 4.0Sv^{-1} respectively [8]. To calculate the equivalent doses to lung and risk of lung cancer from ^{222}Rn and ^{220}Rn, Equilibrium Equivalent Concentration (EEC in Bqm^{-3}) were calculated using equilibrium factors 0.7 for ^{222}Rn and 0.003 for ^{220}Rn [2]. The EECs were then related to Working Level (WL) as; 1 Bqm^{-3} of EEC=0.27 mWL (for ^{222}Rn) and 3.64 mWL (for ^{220}Rn) [2]. The public doses from radon isotopes were estimated using the Working Level Months (WLMs) conversions; 10 mSvWLM^{-1} for ^{222}Rn and 3.4 mSvWLM^{-1} for ^{220}Rn [9]. Furthermore, mean excess relative risk for lung cancer from ^{222}Rn and ^{220}Rn exposures were estimated using 0.26%WLM^{-1} [2]. The outdoor occupancy factor of 0.2 (1752 hrs per year) for gamma as well as ^{222}Rn and ^{220}Rn exposures were taken into account while estimating their respective doses and risks [10, 11].

3. RESULTS AND DISCUSSION

The mean annual effective outdoor doses from ambient absorbed gamma doses as well as ^{222}Rn and ^{220}Rn concentrations and their mean equivalent doses were estimated (Table 1). It is emphasised here that all estimated doses are outdoor values, and in general, indoor doses are expected higher than outdoor. The results of our study showed that, except for Søve, all studied areas had effective gamma doses in range 1.17–2.48 mSv, exceeding mean annual effective dose value in Norway due to the natural external gamma radiation. This is because of the different rocks in the area which contain excessive ^{232}Th concentrations (along with considerable ^{238}U), which are the progenitors of gamma radiation. Since Søve area (the past niobium mining site) was already covered with sand and clay to reduce background radiation from the tailings containing ^{232}Th and ^{238}U, this reduced the gamma dose significantly. The mean value of effective dose due to external natural gamma radiation for Norway is 0.5 mSv [12] while that for global is 0.48 mSv [1]. Comparable mean annual effective doses due to external background radiation, from both indoor and outdoor occupancy (100%), similar to our results were reported for a few high NORM sites worldwide: 6 mSv in Iran, 3.1 mSv in India and 2.1 mSv in China [13]. It should be noted that our results are exclusively of outdoor exposure situations (20% occupancy) unlike mentioned above. Temporal (time spent) and spatial (extent of human contact) factors in relation to the sources of exposures are important to consider while estimating doses.

Table 1. Mean annual effective doses (mSv) from gamma, and ^{222}Rn and ^{220}Rn concentrations (Bqm^{-3}) and their mean equivalent doses (mSv) in the FC areas (mean$\pm$standard deviation).

Areas	Gamma doses	^{222}Rn Conc.	^{222}Rn Doses	^{220}Rn Conc.	^{220}Rn Doses
Bollodalen	1.76 $\pm$0.7	67$\pm$44	1.55$\pm$0.7	1294$\pm$863	0.52$\pm$0.3
Fengruve	2.48$\pm$0.5	62$\pm$60	1.78$\pm$1.0	1442$\pm$1155	0.60$\pm$0.5
Gruvehaugen	2.02$\pm$0.6	52$\pm$36	1.22$\pm$0.5	1786$\pm$860	0.70$\pm$0.2
Rullekoll	1.17 $\pm$0.2	40+26	1.05$\pm$ 0.3	1231$\pm$ 339	0.50$\pm$0.1
Søve	0.36$\pm$0.4	24$\pm$12	0.6$\pm$ 0.1	91$\pm$90	0.03$\pm$0.01

Furthermore, the corresponding mean annual excessive relative risks of different cancers are also estimated (Table 2). The risk of leukaemia from gamma doses was estimated to be higher (0.001-0.01) than that of solid cancer (0.0001-0.001), and lung cancer (0.00002-0.0005) from radon isotopes. It is important to consider that our gamma dose risk estimates are not factual since they were derived from the extrapolation of cancer risks observed from the life span study of survivors of atomic bombings in Hiroshima and Nagasaki. The exposure situation in Hiroshima and Nagasaki was of acute high-dose type, however, the situation in the FC is of chronic low-dose type, therefore, the above risk estimates should be interpreted accordingly.

From the findings of our study, it can be seen that cumulative annual effective doses of gamma, ^{222}Rn and ^{220}Rn exposures to the general public would be more than 1 mSv at all areas of the FC except Søve. This means exposures at those areas are higher than the ICRP's recommended dose limit (1 mSv) to the public. The estimated annual effective dose to the Norwegian population from natural background radiation exposure is 2.9 mSv [5].
It is interesting to see the lower doses from ^{220}Rn as compared to ^{222}Rn. Moreover, the risks from ^{222}Rn and ^{220}Rn doses were also noted almost equal despite having very high ambient ^{220}Rn concentrations as compared to that of ^{222}Rn in the FC areas. This is due to the lower estimated EECs values of ^{220}Rn progeny. However, the doses and risk of ^{220}Rn can be more than 33 times of magnitude what we have estimated now if we would have estimated them using the equilibrium factor of 0.1 as recommended by Kant et al. [14]. Therefore, to estimate the realistic doses and risks from ^{222}Rn and ^{220}Rn, accurate measurement of EECs for both of the radon isotopes in the FC region is necessary.

Table 2. Mean annual excess relative risks of cancers due to gamma, ^{222}Rn and ^{220}Rn doses at the Fen Complex areas.

Areas	Gamma ERRs		^{222}Rn ERRs of Lung Cancer	^{220}Rn ERRs of Lung Cancer
	Solid Cancers	Leukaemia		
Bollodalen	0.0007	0.007	0.0004	0.0004
Fengruve	0.001	0.01	0.0005	0.0004
Gruvehaugen	0.0008	0.008	0.0003	0.0005
Rullekoll	0.0004	0.004	0.0003	0.0004
Søve	0.0001	0.001	0.0001	0.00002

It makes sense here to discuss that the elevated NORM areas in Iran [15, 16], China and India [13, 17] have not shown any increased significant risks from the radiation exposures compared to control population. It is suggested that inhabitants of NORM areas could develop cytogenetic radioadaptive responses [18]. Therefore, it is reasonable to hope that similar response of inhabitants of the FC region is also possible. Due to the small population size in the FC, the epidemiological study of incidence of radiogenic cancers would be difficult. Interestingly, the natural background radiation in Great Britain is said to be causing 15-20% of childhood leukaemia [19]. The average annual natural background radiation dose of the UK population is 2.2 mSv [20]. Besides, indoor radon in the UK

(average conc. of 20 Bqm^{-3}) is estimated to cause 5 % childhood leukaemia and 4% of adult leukaemia [21]. It is believed that any background gamma and/or radon exposures can cause cancers with their effects varying linearly with dose without any threshold.

It is essential to notice that all of the high level radiation sites of the FC are in the distance of 1.12 to 2.23 kilometres from the nearest town, Ulefoss. Ulefoss has 2700 inhabitants [22], while the FC area houses 350 dwellings [5]. Moreover, a high gamma and ^{222}Rn and ^{220}Rn measured site (Gruvehaugen) is located approximately 0.3 km from Fen School. Similarly, the other high gamma exposure sites like Bollodalen, Rulekoll and Gruvehaugen are also not far away from human settlements. Therefore, public utilization of these areas for recreational activities like picnics, etc. is likely, which could pose the health risks depending on the time spent there.

4. CONCLUSIONS

The present study has shown that environmental radiological risk to human population living in the areas of the Fen Complex is likely. The combined risk is due to high natural gamma, ^{222}Rn and ^{220}Rn levels and their possible exposures. According to the ICRP's recommendation, the area would need action to keep the public radiation exposures as low as reasonably achievable in order to reduce the likelihood of any stochastic effects like causation of cancers or mutations.

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